DESCRIPTION

Loop-Type Thermosiphon and Stirling Refrigerator

Technical Field

The present invention relates to a loop-type thermosiphon and a Stirling refrigerator using the same.

Background Art

A heat sink, a heat pipe, a thermosiphon, or the like is used for cooling a heat-generating instrument or a thermoelectric cooling device. As to the heat sink, temperature distribution is caused in a base portion thereof provided with a heat source. Accordingly, as a distance from the heat source is increased, the heat sink contributes less to heat dissipation. Meanwhile, the heat pipe or the thermosiphon has high heat transfer capability, and is characterized by small temperature variation even when the heat is transferred to a portion distant from the heat source.

On the other hand, with regard to the heat pipe, vapor and liquid of a working fluid flows in the same pipe. As such, if an amount of heat transfer is large, a greater number of pipes are necessary. For example, if it is assumed that a temperature difference is set to 5°C, a heat pipe having an outer diameter of 15.8mm and a length of 300mm attains an amount of heat transfer of approximately 100W. If the heat should ultimately be emitted to an atmospheric environment, a heat pipe including a condensation portion having a large heat transfer area should be provided in order to exchange heat with air, because a heat transfer coefficient of the air is low. A pipe-shaped thermosiphon in which a liquid returns to an evaporation portion by gravity also has the similar characteristic.

Meanwhile, a loop-type thermosiphon is also structured such that the liquid condensed in a condenser returns to an evaporator by gravity. Here, however, not only a shape and a size of the condenser can be designed in accordance with cooling means

of the condenser, but also the evaporator can be designed in accordance with a shape and a size of the heat source. Therefore, two pipes, i.e., a gas pipe and a liquid pipe connecting the condenser and the evaporator are enough in most cases. Here, it is natural that the condenser has to be located above the evaporator.

In the loop-type thermosiphon, however, circulation flow rate is less likely to be stabilized and a temperature of the heat source tends to fluctuate in many cases, depending on a type of a contained working fluid or heat load fluctuation in a certain range. As is well-known, a CFC (chlorofluorocarbon) and an HCFC-based refrigerant have been used as a working fluid or as a secondary working fluid in cooling equipment. The CFC-based refrigerant, however, is no longer used, and the use of the HCFC-based refrigerant is restricted under the international treaty for protecting ozone layer. In addition, a newly developed HFC-based refrigerant, though not destroying the ozone layer, is a potent greenhouse substance attaining a global warming coefficient several hundred to several thousand or more times larger than carbon dioxide, and subject to effluent control. Therefore, types of refrigerants that can be selected as a working fluid for the loop-type thermosiphon are limited from a viewpoint of environmental protection. Examples of an environmental-friendly and what is called natural refrigerant include a medium such as an HC-based refrigerant, ammonia, carbon dioxide, water, and ethanol, and a mixture thereof.

As shown in Fig. 5, a conventional loop-type thermosiphon is structured by connecting an evaporator 101, a condenser 103 and a gas-liquid separation tank 106 using pipes 102, 104. A heat source 105 is cooled in evaporator 101. Condenser 103 is provided above evaporator 101. The working fluid liquefied in condenser 103 is separated to gas and liquid in gas-liquid separation tank 106 provided between the condenser and the evaporator. The liquid of the working fluid runs through pipe 104 by gravity, and is introduced in the evaporator from a lower portion of evaporator 101. In addition, the working fluid that has deprived the heat source of heat is vaporized in evaporator 101, and the vapor of the working fluid is introduced in condenser 103 through pipe 102 by a vapor pressure difference between the condenser and the

evaporator. In most cases, evaporator 101 is designed in accordance with the shape of the heat source. In Fig. 5, gas-liquid separation tank 106 is not essential.

Japanese Patent Laying-Open No. 11-223404 discloses a method of cooling a high-temperature portion of a Stirling cooler with a liquid of a secondary refrigerant by means of a pump.

In the conventional loop-type thermosiphon, however, unstable circulation flow rate of the working fluid has been likely, resulting in fluctuation of the temperature of the heat source. In particular, if the conventional loop-type thermosiphon is operated under a load far from a target load in accordance with design, the temperature of the heat source often fluctuates significantly. If the temperature of the heat source fluctuates significantly, not only performance of heat source equipment becomes unstable, but also the heat source equipment may be damaged.

Here, it is assumed that the loop-type thermosiphon is utilized for cooling a high-temperature portion of a Stirling cooler and the Stirling cooler is mounted on a refrigerator, for example. As is well-known, heat load of the refrigerator fluctuates depending on the season. When the heat load of the refrigerator fluctuates, an amount of heat dissipation from the high-temperature portion of the Stirling cooler is also varied. The loop-type thermosiphon often exhibits an unstable operation under fluctuating heat load. Here, if the temperature of the high-temperature portion of the Stirling cooler fluctuates significantly, an influence therefrom is not limited to fluctuation of a COP (Coefficient of Performance) of the Stirling cooler. If the temperature of the high-temperature portion is excessively high, a regenerator of the Stirling cooler may be destroyed.

Fig. 6 shows an evaporator for the conventional loop-type thermosiphon cooling the heat source having a cylindrical shape. Evaporator 101 has an annular shape in order to cool cylindrical heat source 105. Cylindrical heat source 105 is fitted in a hole of the evaporator, so as to be in intimate contact with a surface of the hole of the evaporator. The surface of the hole of the evaporator is provided with an internal fin (not shown) for increasing an evaporation area. The liquid from the condenser runs

through pipe 104 and flows into a liquid pool 121 through a lower portion of the evaporator, and the vapor exits from an upper portion of the evaporator through pipe 102 and flows to the condenser.

Fig. 7 shows variation of the temperature of the heat source in an experimental operation of the loop-type thermosiphon employing the evaporator and the pipe arrangement shown in Fig. 6 and containing water as a working fluid. If an amount of heat generation from the heat source is not larger than 75% of designed load, fluctuation of the temperature of the heat source is caused as shown in Fig. 7. Improvement was not observed even when a contained amount of the working fluid was changed.

An object of the present invention is to provide a loop-type thermosiphon capable of maintaining a stable temperature of a high-temperature heat source in spite of large fluctuation of heat load and a Stirling refrigerator equipped with the same.

Disclosure of the Invention

A loop-type thermosiphon according to the present invention transfers heat from a cylindrical high-temperature heat source using a working fluid. The loop-type thermosiphon includes: an annular evaporator having a heat absorption portion attached to the high-temperature heat source and evaporating the working fluid by depriving the high-temperature heat source of heat through the heat absorption portion; a condenser located above the high-temperature heat source and condensing the working fluid that has evaporated in the evaporator; and a pipe connecting the evaporator and the condenser so as to form a loop. The working fluid that has passed through the condenser and has been condensed is made to fall on the heat absorption portion before it is pooled in a liquid pool for the working fluid in the evaporator.

According to such an arrangement, the cooled and condensed working fluid is preheated after falling on the heat absorption portion instead of being directly supplied to the liquid pool, and thereafter it is supplied from above by gravitation. Accordingly, a flow is produced in the liquid pool and evaporation of the working fluid as a whole,

including the working fluid in the liquid pool, is promoted. Naturally, evaporation of the working fluid that has been introduced and initially exchanges heat with the heat absorption portion is also promoted in an ensured manner, whereby temperature distribution in the high-temperature heat source can be uniform. In addition, separation of bubbles adhered to the heat absorption portion or the like can be promoted. Therefore, heat exchange adapted to fluctuation of the heat load can be performed, and the temperature of the high-temperature heat source can be stabilized. In addition, as the high-temperature heat source has a cylindrical shape and the evaporator has an annular shape, an apparatus having a compact structure and ensuring heat exchange efficiency can readily be manufactured.

Brief Description of the Drawings

Fig. 1 illustrates a basic arrangement of a loop-type thermosiphon in a first embodiment of the present invention.

Fig. 2 shows a variation of the loop-type thermosiphon in the first embodiment of the present invention.

Fig. 3 shows a Stirling refrigerator in a second embodiment of the present invention.

Fig. 4 shows stability of a temperature of a heat source when a loop-type thermosiphon in a third embodiment of the present invention is employed.

Fig. 5 shows an arrangement of a general loop-type thermosiphon.

Fig. 6 shows an evaporator in a conventional loop-type thermosiphon.

Fig. 7 shows fluctuation of a temperature of a heat source when the conventional loop-type thermosiphon is used.

Best Modes for Carrying Out the Invention

In the following, embodiments of the present invention will be described with reference to the figures.

(First Embodiment)

Fig. 1 is a conceptual diagram illustrating a basic arrangement of a loop-type thermosiphon in a first embodiment of the present invention. The loop-type thermosiphon shown in Fig. 1 is constituted of an evaporator 1, a condenser 3, a gas pipe 2 extending from evaporator 1 to condenser 3, and a liquid pipe 4 extending from condenser 3 to evaporator 1. In the present embodiment, as a high-temperature heat source 5 to be cooled has a cylindrical heat dissipation surface as shown in Fig. 1, the evaporator has an annular shape with a circular hole having a dimension adapted to the cylindrical heat dissipation surface of the heat source. In addition, a surface of the hole of the evaporator is brought in intimate contact with the cylindrical heat dissipation surface of heat source 5 in order to reduce thermal contact resistance. Condenser 3 is of a fin-tube type, and cools a working fluid flowing inside the pipe by flowing air around the same.

The pipe of the condenser for flowing the working fluid may be any of a parallel flow type and a serpentine type. The condenser is provided such that an inlet of a gas is located higher than an outlet of a condensed liquid. Gas pipe 2 extending from evaporator 1 to condenser 3 has a larger diameter than liquid pipe 4 extending from the condenser to the evaporator. Therefore, gas pipe 2 has a flow resistance smaller than liquid pipe 4, so as to prevent backflow of the working fluid and hard starting. A diameter of the liquid pipe is determined based on designed heat load and thermal property of the working fluid. In order to form a thermosiphon, condenser 3 is located above evaporator 1.

In the present embodiment, pure water is contained as the working fluid. Here, a contained amount is assumed as a mass of the working fluid of which liquid fills 1/3 to 2/3 of a total of a possible volume of liquid pool in the condenser (a header pipe at an outlet of the condenser, for example), a volume of the liquid pipe and a volume of the evaporator, and of which saturated vapor fills a remaining volume at an operating temperature. Such a contained amount allows smooth operation of the working fluid.

As to the operation, as shown in Fig. 1, the water evaporates by depriving high-temperature heat source 5 of heat in evaporator 1. The vapor produced in evaporator 1

runs through gas pipe 2 utilizing a vapor pressure difference caused by a temperature difference between condenser 3 and evaporator 1 and flows in condenser 3, in which the vapor is deprived of heat by the air outside the pipe and condensed. The liquid condensed in condenser 3 returns to evaporator 1 through liquid pipe 4 by gravity. In this manner, a process including circulation of the working fluid, heat absorption in the evaporator, and heat dissipation in the condenser is repeated.

One feature of the embodiment of the present invention resides in introduction of the liquid from the condenser through the upper portion of the evaporator as shown in Fig. 1, instead of introduction through the lower portion thereof (see Fig. 5). In the arrangement of the conventional loop-type thermosiphon shown in Figs. 4 and 5, a cold liquid is supplied to the lower portion of the evaporator. Accordingly, a temperature gradient in the liquid pooled in the evaporator does not considerably affect the flow, without promoting evaporation. If the evaporator operates under a condition far from the designed heat load, particularly under such a condition as small heat load, bubbles adhered to a heat transfer surface takes longer time in growth. Then, the liquid is further pooled in the evaporator and the bubbles are less likely to escape. As described above, in the conventional thermosiphon, significant temperature fluctuation is caused in the heat source due to variation of circulation flow rate of the working fluid or suspension of circulation (see Fig. 7).

In the loop-type thermosiphon in the present embodiment shown in Fig. 1, the liquid from the condenser is introduced through the upper portion of the evaporator, so that the supercooled liquid initially falls on a heat absorption portion at a high temperature or on a not-shown internal fin, on which the liquid is preheated. The internal fin is attached to the heat absorption portion and formed inwardly, so that evaporation of the liquid pooled in the evaporator is promoted. In addition, when a colder liquid is introduced from above the liquid level in the evaporator, the liquid tends to move downward by gravity due to a difference in density. Then, the liquid in the evaporator is stirred and evaporation is promoted, whereby the bubbles present on the heat transfer surface tend to be separated and destroyed. In this manner, the loop-

type thermosiphon according to the present embodiment can achieve a stable temperature of the heat source even under a condition far from the designed heat load.

Though the gas-liquid separation tank is not provided in the loop-type thermosiphon shown in Fig. 1, a gas-liquid separation tank 6 may be provided between the condenser and the evaporator as shown in Fig. 2. It is noted, however, that an inner volume of the gas-liquid separation tank should be regarded as a portion of the liquid pipe in determining a contained amount. Provision of the gas-liquid separation tank may be effective for attaining a stable operation of the loop-type thermosiphon.

Addition of ethanol to the water serving as the working fluid by not larger than 60% can lower a tolerable temperature of an environment during operation or transportation.

(Second Embodiment)

Fig. 3 is a conceptual diagram of a Stirling refrigerator according to a second embodiment of the present invention, provided with the loop-type thermosiphon. The Stirling refrigerator in Fig. 3 is constituted of a Stirling cooler provided in a refrigerator main body 19, the loop-type thermosiphon attached in order to cool a high-temperature portion of the Stirling cooler, a low-temperature side heat exchange system transferring a cold of a low-temperature portion of the Stirling cooler to the inside of the refrigerator, the refrigerator main body, and the like. Though the low-temperature side heat exchange system is implemented by the loop-type thermosiphon, it is the loop-type thermosiphon not of interest in the present embodiment.

A Stirling cooler 11 having cylindrical high-temperature and low-temperature portions is arranged on a back surface of the refrigerator. Evaporator 1 of the loop-type thermosiphon cooling a high-temperature portion 13 of the Stirling cooler is attached to and brought in intimate contact with the high-temperature portion of the Stirling cooler. In addition, condenser 3 is placed on the refrigerator main body and evaporator 1 and condenser 3 are connected to each other by a pipe as shown in Fig. 1, so that the loop-type thermosiphon in the present embodiment is mounted on the Stirling refrigerator. Liquid pipe 4 is inserted in evaporator 1 through its upper

portion. As a working fluid, pure water or a mixture of pure water and ethanol is contained.

The low-temperature side heat exchange system supplies the cold of a low-temperature portion 12 of the Stirling cooler to the inside of the refrigerator with a refrigerator cooling apparatus 15 utilizing a secondary refrigerant. Refrigerator cooling apparatus 15 is provided in a cold-air duct in the refrigerator.

When Stirling cooler 11 operates, the temperature of high-temperature portion 13 of the Stirling cooler is raised. Then, the working fluid is heated and evaporates in evaporator 1 and flows in condenser 3 through gas pipe 2. At the same time, outside air is introduced by rotation of a fan 7, so that the gas of the working fluid from evaporator 1 is cooled and condensed in condenser 3. The working fluid liquefied in condenser 3 returns to evaporator 1 through liquid pipe 4 and an introduction pipe 4a by gravity. When the liquefied working fluid returns to evaporator 1, the working fluid comes in contact with a heat absorption portion 1a and/or the internal fin (not shown) of the evaporator so as to exchange heat. In this manner, natural circulation of the working fluid is attained and the heat of Stirling cooler 11 is transferred to the outside air.

The operation of Stirling cooler 11 serves to lower the temperature of low-temperature portion 12, and the secondary refrigerant in the heat exchange system flowing through the low-temperature portion is deprived of heat. On the other hand, the secondary refrigerant in the low-temperature side heat exchange system absorbs heat from the air inside the refrigerator in the refrigerator cooling apparatus by rotation of a cooling fan 16 on which a damper 17 is arranged. In the present embodiment, the secondary refrigerant in the low-temperature side heat exchange system attains natural circulation by gravity. Alternatively, circulation may naturally be attained by circulation means using a pump. As described above, the cold of Stirling cooler 11 is continuously provided to the air inside the refrigerator.

In addition, drain water resulting from defrosting of refrigerator cooling apparatus 15 is discharged from a drain water outlet 18.

(Third Embodiment)

Fig. 4 shows temperature fluctuation of the high-temperature heat source when a loop-type thermosiphon according to a third embodiment of the present invention is employed. The loop-type thermosiphon in the present embodiment is obtained merely by varying a manner of return of the liquid to the evaporator in the conventional loop-type thermosiphon shown in Fig. 6. In other words, the loop-type thermosiphon is structured such that the condensed working fluid is returned so as to contact with the heat absorption portion not being in contact with the liquid pool, instead of being directly introduced into the liquid pool.

The variation with time of the temperature of the high-temperature heat source shown in Fig. 4 exhibits an effect obtained under the condition of heat load the same as in the conventional loop-type thermosiphon. As compared with the large temperature fluctuation of the heat source in the conventional loop-type thermosiphon shown in Fig. 7, stable temperature transition can be achieved.

Examples as many as possible including those mentioned in the first to third embodiments of the present invention will comprehensively be explained, referring to effects of the loop-type thermosiphon and the refrigerator in each embodiment of the present invention.

In one embodiment of the present invention, a loop-type thermosiphon transferring heat from a high-temperature heat source having a heat dissipation surface includes an evaporator depriving the high-temperature heat source of heat, a condenser arranged above the high-temperature heat source, and a pipe connecting the evaporator and the condenser so as to form a loop. The loop-type thermosiphon contains a working fluid, and drops the liquid of the working fluid from the condenser on a heat absorption portion when it is introduced in the evaporator, so as to exchange heat. Therefore, a loop-type thermosiphon capable of maintaining a stable temperature of the high-temperature heat source can be provided.

In addition, in one embodiment according to the present invention different from that described above, an internal fin is provided in the heat absorption portion in

the evaporator constituting the loop-type thermosiphon, and the liquid of the working fluid condensed in the condenser is introduced in the evaporator through the upper portion thereof, so that the liquid of the working fluid falls on the heat absorption portion or the internal fin in the evaporator. Here, the evaporator may have a box-shape, or may have an annular shape by combining semi-annular portions. Alternatively, combination of portions of another shape may be employed. The heat absorption portion may be of a cylindrical shape or formed like a hole so as to receive the high-temperature heat source. According to the structure as above, utilizing in the evaporator the heat from an upper half of a cylindrical heat dissipation surface of the high-temperature heat source of which heat dissipation amount is not as large as that in a lower half thereof, the liquid of the working fluid can be preheated and a uniform and stable temperature of the high-temperature heat source in the evaporator can be achieved.

In an arrangement of a loop-type thermosiphon according to another embodiment of the present invention, a flow resistance of the gas pipe guiding vapor produced in the evaporator to the condenser is made smaller than that of the liquid pipe guiding the liquid condensed in the condenser to the evaporator. According to such an arrangement, backflow of the working fluid and hard starting likely in the thermosiphon can be prevented.

Moreover, in one embodiment of the present invention other than those as above, desirably in accordance with an amount of heat transferred from the high-temperature heat source, the flow resistance of the pipe is made smaller if the amount of transferred heat is large, and it is made larger if the amount of transferred heat is small. If a diameter of the pipe is determined based on such an arrangement, more stable circulation flow rate of the working fluid can be achieved. Here, a reference value of magnitude of an amount of transferred heat may be set to 75% of the designed load, for example. That is, if an amount of heat generation from the heat source is not larger than 75% of the designed load, the flow resistance of the pipe is made larger, and if it exceeds 75%, the flow resistance of the pipe is made smaller. Alternatively, another

reference value such as 50% of the designed load may be adopted.

In a loop-type thermosiphon according to another embodiment of the present invention, a contained amount of the working fluid can be set to a mass of the working fluid of which liquid fills 1/3 to 2/3 of a total of a possible volume of liquid pool in the condenser at an operating temperature, a volume of the liquid pipe (the pipe) and a volume of the evaporator, and of which saturated vapor fills a remaining volume at the operating temperature. Accordingly, a disadvantage resulting from a contained amount of the working fluid can be eliminated.

A loop-type thermosiphon according to yet another embodiment of the present invention employs a natural refrigerant such as carbonic acid gas, water, hydrocarbon, or the like as the working fluid, and can provide an environment-friendly heat exchange technique. Particularly when water is employed as the working fluid, a safe loop-type thermosiphon free from a toxic or flammable property can be obtained. Addition of ethanol by not larger than 60% can expand a range of temperature in an environment in which the loop-type thermosiphon employing water as the working fluid can operate.

In a refrigerator equipped with a Stirling cooler employing the loop-type thermosiphon according to any one of the embodiments of the present invention described above, the evaporator of the loop-type thermosiphon described above exchanges heat with the high-temperature portion of the Stirling cooler. Specifically, both of these components are brought in intimate contact with each other. In addition, the condenser can be arranged in a position higher than that of the high-temperature portion of the Stirling cooler of the refrigerator. According to such an arrangement, even when heat load of the Stirling refrigerator is varied, the Stirling cooler can achieve a stable operation. In addition, as the working fluid achieves natural circulation by gravity, it is not necessary to provide a pump. Therefore, high reliability and efficiency can effectively be achieved.

The effects in each embodiment of the present invention have been enumerated and explained. In the present invention, however, a loop-type thermosiphon according to an embodiment covering a broadest scope does not have to attain all effects in each

embodiment described above. The loop-type thermosiphon in the embodiment covering the broadest scope should only achieve a stable operation adapted to fluctuation of load of the heat source.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

Industrial Applicability

The loop-type thermosiphon according to the present invention can absorb fluctuation of heat load of the heat source and attain a stable operation. Therefore, the loop-type thermosiphon described above is used for cooling the high-temperature portion of the Stirling cooler in the refrigerator employing as a cooling apparatus the Stirling cooler without using CFC and free from greenhouse gas emission, for example. The loop-type thermosiphon is expected to contribute to ensuring stable freezing performance throughout a year.